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REVIEW

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Duration of deafness impacts auditory performance after cochlear implantation: A meta-analysis

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Abstract

Objective: Hearing loss is a highly disabling condition. Cochlear implantation is an established remedy if conventional hearing aids have failed to alleviate the level of disability. Unfortunately, cochlear implant (CI) performance varies dramatically. This study aims to examine the effects of duration of deafness (DoD) prior to cochlear implantation and the postoperative duration of implant experience with resulting hearing performance in postlingually deaf patients.

Methods: A systematic literature review and two meta-analyses were conducted using the search terms *cochlear implant* AND *duration deafness*. Included studies evaluate the correlation between the DoD and auditory performance after cochlear implantation using monosyllabic and sentence tests. Correlation coefficients were determined using Pearson's correlation and Spearman rho.

Results: A total of 36 studies were identified and included data on cochlear implantations following postlingual deafness and postoperative speech testing of hearing outcomes for 1802 patients. The mean age ranged from 44 to 68 years with a DoD of 0.1 to 77 years. Cochlear implant use varied from 3 months to 14 years of age. Speech perception, which was assessed by sentence and monosyllabic word perception, was negatively correlated with DoD. Subgroup analyses revealed worse outcomes for longer DoD and shorter postoperative follow-up.

Conclusion: DoD is one of the most important factors to predict speech perception after cochlear implantation in postlingually deaf patients. The meta-analyses revealed a negative correlation between length of auditory deprivation and postoperative sentence and monosyllabic speech perception. Longer DoD seems to lead to worse CI performance, whereas more experience with CI mitigates the effect.

KEYWORDS
Cochlear implantation, duration of deafness, hearing loss, speech perception

Toni Hänsel and Annekatrin Coordes contributed equally.

1 | INTRODUCTION

Hearing loss is the third most prevalent condition in high and middle-income countries and ranks #10 in disorders causing the most disability-adjusted life years according to the Global Burden of Disease project.[1] In cases of severe hearing loss, low speech discrimination or little benefit from hearing aids, patients may be eligible for a cochlear implant (CI).[2] The predictability of CI outcome has been thoroughly investigated. Among other things, patient related factors, etiology and duration of deafness (DoD) prior to implantation contribute 40% to the variance of CI performance.[3,4]

The World Health Organization defines deafness as a profound hearing impairment (> 81 dB between 0.5 and 4 kHz).[5] DoD is the number of years of profound hearing loss before implantation. The impact of auditory deprivation and DoD on postoperative performance has to be taken into account while counseling suitable candidates for CI.[6-8] Positron emission tomography results show a correlation between degree of cortical activation and speech therapy results.[9,10] Cochlear implantees who have used acoustic hearing aids before cochlear implantation tend to have better hearing results than those who have not used a hearing aid preoperatively.[11-14] These discussions address preoperative considerations regarding which ear is most suitable for cochlear implantation.[15,16]

Various studies have investigated the impact of DoD on auditory performance after cochlear implantation with contradictory results[17,18] and tried to determine specific criteria for CI candidacy, such as a DoD limit or specified age at implantation.[19-21] The question was if a long DoD is associated with worse auditory performance and if increasing experience/use of CI improves the outcome. Therefore, the aim of the current meta-analysis is to evaluate the effect of DoD on speech perception after cochlear implantation in postlingually, bilaterally deaf patients according to the available literature.

2 | METHODS

2.1 | Literature search strategy and selection criteria

We searched for published literature evaluating the correlation between DoD and auditory performance after cochlear implantation using monosyllabic and sentence tests of postlingually deafened CI recipients. Correlation coefficients were determined using Pearson's correlation and Spearman rho. Figure 1 presents a flowchart of the search strategy and the inclusion criteria for the selected studies.

A literature search was performed according to the PRISMA statement[22] until the 20th February 2020 in Pubmed, Embase, Cochrane Library and Cinahl via EBSCOhost. The study was registered in the PROSPERO register (CRD42017070525). The following search terms were used: *cochlear implant* AND *duration deafness*. Additionally, we checked references cited in original or review articles that were not retrieved from the databases by the initial literature search.

In a first selection, both English and German publications were screened and all studies reporting on patients with cochlear implantation and postlingual deafness (age at onset of deafness ≥5 years) were included. Exclusion criteria consisted of reviews, case reports and case series (<12 subjects), histopathological or animal studies, single-sided deafness or asymmetric hearing loss with bimodal CI system in patients with residual hearing, reimplantation, temporal bone fractures and sequential second ear CI. Outcomes determined by tests including lip-reading and other visual stimuli were also excluded.

In a second, more detailed selection, full-text articles were assessed for sufficient data according to the inclusion criteria. More recent studies or those with larger patient numbers were chosen. Studies focusing on prelingual or congenital cases and where language development was a major factor were excluded. To increase eligibility for the meta-analysis, studies with a maximum of 15% prelingual or congenital cases were included when the inclusion criteria were otherwise met.

2.2 | Data extraction

The screening and the selection of the studies were performed independently by three of the authors N.B., T.H. and A.C. Ambiguous studies were discussed and included if consensus was reached. The onset of hearing loss was defined by patient history and objective diagnostics. If no correlation coefficient was presented but ample data was available,[23-35] information on DoD and speech perception would be extracted, while patients with prelingual onset of deafness before the age of 5,[23,25,26,32] data of sequential implantations[28] and duplicate patient data[30,31] were excluded. Data was also obtained from published figures and graphs.[25,30,34]

2.3 | Statistical analysis

When individual patient data was extracted, it was checked for normal distribution and linearity, using graphic presentation with scatter plot, histograms and calculation of Shapiro-Wilk normality test. Pearson's correlation was calculated if normal distribution and linearity were present, otherwise Spearman rho was calculated.

For the meta-analysis, we included studies presenting Pearson or Spearman correlation coefficients on DoD and postoperative speech perception tests at the latest follow-up visit. For better comparability, we converted Spearman rho into Pearson's correlation coefficient using Rupinski's equation[36] from eligible studies.[8,15,26,29,35,37-43]

The comparability of the analyzed studies was tested for heterogeneity with Cochrane's *Q*-test. A *P*-value above .05 represented an absence of heterogeneity between studies. Statistical heterogeneity of studies was assessed by calculating I^2 index and tau.[2] $I^2 < 20\%$ was defined as an indication of homogeneity, thus the fixed effect model (Mantel Haenszel) was applied. The random effects model (DerSimonian and Laird) was used if heterogeneity was present. A forest plot compared the included studies investigating DoD and postoperative auditory performance.

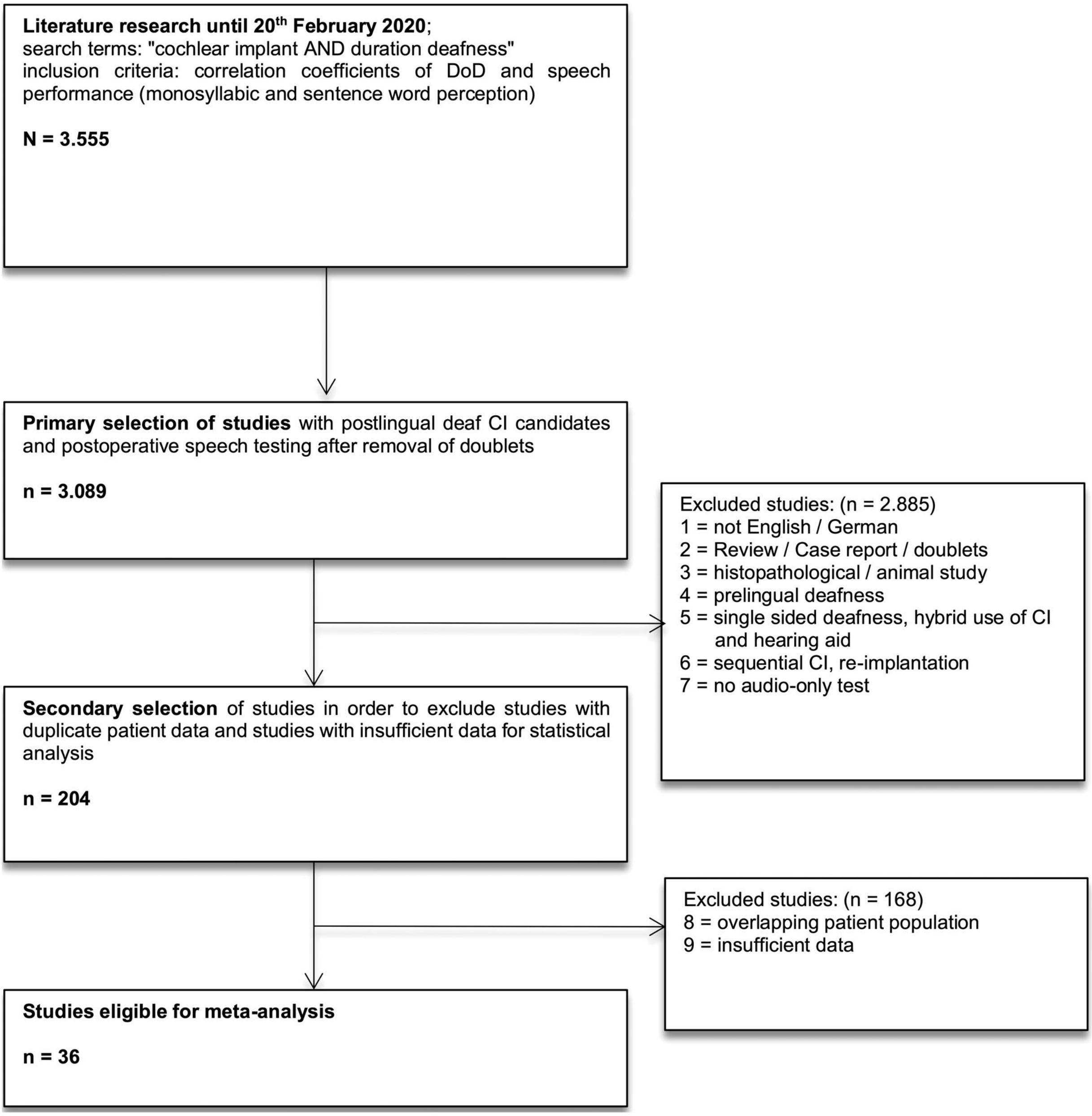

FIGURE 1 Flowchart of systematic literature search. The figure shows the search strategy and criteria for inclusion and selection of the investigated studies

Subgroup analysis was performed to test for possible effects resulting from differences in the time of postoperative testing and DoD. The significance of any difference was judged according to Fisher's z-transformation at a value of $P \leq .05$. The degree of correlation was classified according to the correlation value and was classified as a strong (between ±0.50 and ±1), medium (between ±0.30 and ±0.49) or small correlation (below ±0.29).

To test the robustness of our results, we performed a sensitivity analysis and included 50% of the more recent publications. The risk of bias was assessed using a modified QUADAS-2 tool,[44] which analyses 4 domains: patient selection, speech tests, definition of deafness, flow and timing. Speech tests were analyzed for conduction and interpretation. Concerns regarding applicability were assessed for the first 3 domains.

Begg's funnel and Egger's test were performed to assess publication bias.

For statistical computing and graphics, we worked with the free software environment R version 3.6.3.

3 | RESULTS

3.1 | Description of the included studies

A total of 36 studies in 3555 publications were identified and included data on cochlear implantations following postlingual deafness and postoperative speech testing of hearing outcomes for 1802 patients

TABLE 1 Patient characteristics

Study	Country	n[a] (mono/sentence)	Mean age (with SD)	Mean DoD (with SD)	Range DoD (years)	Mean postop time (months)	Speech perception test[b]
Anderson, 2019	UK	/6	65.8 ± 13.2	28.3 ± 15.0	0.3-59	6	CUNY
Arenberg, 2018	USA	10/	62.9 ± 11.4	9.6 ± 12.3	0-41	98	V
Battmer, 1997	Germany	168/	44.3 ± 11.6	9.7 ± 11.7	0.2-56.1	60	F
Beyea, 2016	USA	/24	60.3 ± 15.4	23.1 ± 13.8		77	HINT, AzBio
Blamey, 1992	Australia	/61	66.4 ± 15.1	23.1 ± 13.8	1-53	3	CID
Bredberg, 2003	international	21/21		16.4 ± 11.9	3-52	18	M, S
Derinsu, 2019	Turkey	76/		17.8 ± 9.87	1-77	15	M
Dorman, 1989	USA	41/50	46	11.5	1-49	12	NU-6, CID
Fetterman, 2002	USA	/96	53 ± 12.8	6.25 ± 7.76	0.5-12	42	CUNY
Franck, 2001	USA	/12	52	17		3	CUNY
Gantz, 1988	USA	/39				9	Iowa
Goehring, 2019	UK	/7	62.4 ± 9.03	31.5 ± 18.7	3-64	72	BKB
Gomaa, 2003	USA	67/		± 9.5	0.1-56	5	CNC
Han, 2019	South Korea	36/	44.5 ± 11.4	8.3 ± 9.7	0.2-37	12	M
Hay-McCutcheon, 2005	USA	/17	46	19	2-41	12	HINT
Hiraumi, 2007	Japan	109/109	52.8 ± 17.1	7.6 ± 10.6	0.1-40	6	CV, S
Hirschfelder, 2008	Germany	54/54	50.2 ± 14.4	10.2 ± 10.8	0.5-34	48	F, HSM
Holden, 2013	USA	92/	57.4 ± 16.3	13.1 ± 11.3	0.5-45	24	CNC
Ishino, 2018	Japan	22/	67.1 ± 13.2	6.21 ± 6.63		101	BMD
Jahn, 2019	USA	12/	62.4 ± 19.3	17.8 ± 13.5	4-46	100	V, C
Jahn, 2020	USA	7/	65.4 ± 8.97	23.4 ± 20.5	1.3-61.2	88	V
Kelly, 2005	New Zealand	12/12	50.3 ± 13.7	5.5 ± 4.4	1-15	35	CNC, HINT
Lee, 2019	USA	/12	57.1 ± 13.7	12.6 ± 15.1		6	AzBio
Matterson, 2007	Australia	29/30	66	23	1-59	12	CNC, CUNY
Medina, 2017	Spain	103/103	53.1	9.5	1-43	36	V, S
Oh, 2003	South Korea	/13		8.8	0.25-24	48	K-CID
Parkin, 1989	USA	/20	45.5 ± 13.6	10.1 ± 9.95	1-42	12	CID
Roditi, 2009	USA	52/	62 ± 15.3	11.6 ± 11.2	0.5-49	28	CNC
Ruffin, 2007	USA	29/	49.9 ± 14.2	8.9 ± 11.2	0-45	59	CNC, NU-6
Shea, 1990	USA	20/20	47.7 ± 15.9	15 ± 13.9		9	NU-6, CID
Suh, 2015	South Korea	/15	64.7 ± 5.1	9.5 ± 12.4		12	K-CID
UKCISG, 2004	UK	/295	52.5	13.2		9	BKB
van der Marel, 2015	Netherlands	162/	56 ± 15	22 ± 18		18	M
van Dijk, 1999	Netherlands	37/	46.1 ± 14	14.9 ± 14	1.5-47	9	FS-A
Wasmann, 2018	Netherlands	8/	62.1 ± 14.5	22 ± 13.1	3-45	48	CVC
Zhou, 2019	USA	/8	67 ± 7.32	8.31 ± 15.4	0.3-47	62	CUNY

[a]Only number of postlingual deaf patients with available data on speech perception and DoD; mean age and mean DoD was calculated according to selected group if possible.

[b]Abbreviations: BKB, Bamford-Kowal-Bench speech corpus; C, consonant; CID, Central Institute of Deafness sentence test score; CNC, Consonant-Vowel Nucleus-Consonant words; CUNY, City University of New York Sentence Lists; DoD, duration of deafness; FS-A, combination of consonant-vowel-consonant words open set test + environmental sounds + Spondee; F, Freiburger Monosyllabic Test; HSM, Hochmair, Schulz, Moser sentence test; K-CID, Korean CID; M, monosyllabic; NU-6, Northwestern University Monosyllabic Word Test; S, sentence; V, vowel.

(Table 1). All articles were published between 1987 and 2020. The patients' mean age ranged from 44 to 68 years with a DoD range of 0.1 to 77 years. Most studies were performed in the Unites States (17 studies, with 558 included patients), followed by the United Kingdom (3 studies, 308 patients) and the Netherlands (3 studies, 270 patients).

The CI use and point in time of testing ranged from between 3 months to 14 years after implantation.

Twenty-two studies with 1167 patients presented data on vowel/consonant and monosyllabic word perception scores, namely the best monosyllabic discrimination (BMD) score,[41] the Consonant-Nucleus-Consonant (CNC) words,[4,35,38,45-47] Consonant-Vowel tests,[31,32,37,48] the Northwestern University Auditory Test No.6 (NU-6),[29,35,49] Freiburg monosyllabic word test,[34,40] vowel identification score[30,39,50], a word perception test[15,51,52] and different tests.[24]

Data on speech perception measured by sentence-tests was available from 22 studies with 1024 patients. The following tests were used: the AzBio Sentence Test,[19,26] the Hearing in Noise Test (HINT),[19,46,53] Bamford-Kowal-Bench sentences (BKB),[25,42] Central Institute of the Deaf sentences (CID),[29,49,54,55] its Korean version K-CID,[8,43] City University of New York sentences (CUNY),[23,28,47,56,57] Iowa Sentence Test,[58] Hochmair-Schulz-Moser test,[40] a Japanese phrase intelligibility test,[37] a Spanish sentence test[39] and unspecified tests.[24] Monosyllabic and sentence tests were separately analyzed. Subgroup analyses of individual tests were performed and their results compared with the whole data set to confirm the robustness of the data. Zokoll et al. and Bredberg et al. have confirmed that hearing tests in different languages are comparable.[24,59]

3.2 | Definitions of deafness and its duration

The definition of deafness also varied across all studies. Francis et al. classified deafness according to pure tone averages as bilateral severe, severe-profound (severe in one ear and profound in the other), and bilateral profound hearing loss.[60] Other authors used pure tone audiograms of the point in time when hearing loss was first diagnosed to define the onset of deafness.[4,19,45,53] The UK Cochlear Implant Study Group defined duration of profound deafness as severe or profound sensorineural hearing impairment of 70 dB (0.5-4 kHz) in the better-hearing ear.[42] To estimate DoD, they used a patient's self-rating method proposed by Lutman et al[61] Some of the studies included define the onset of deafness based on different subjective methods reported by patients,[4] for example, the inability to communicate via telephone[7,39] and/or having no or very little benefit from hearing aids.[19,24,29,37,39,49,58,62] Consequently, there is a high probability for recall bias, particularly considering those patients with a progressive onset of deafness.

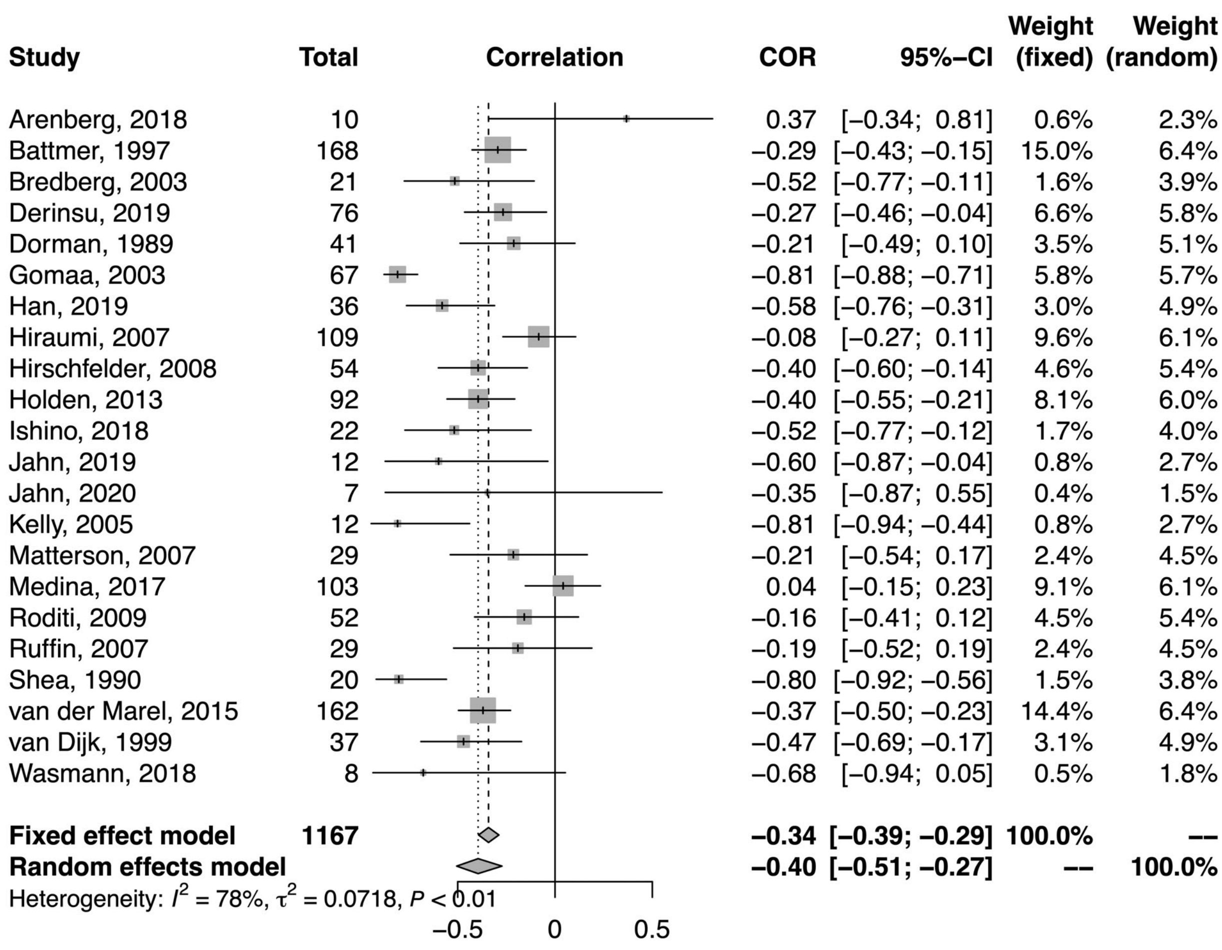

FIGURE 2 Meta-analysis of monosyllable tests. The forest-plot indicates the correlation between the preoperative duration of deafness and the postoperative scores of speech tests for monosyllables. Total: number of investigated patients

3.3 | Meta-analyses

The meta-analysis investigating the association of monosyllabic speech perception test results and DoD in 22 studies with 1167 patients showed a medium negative correlation (Random effects model; COR −0.40; 95%—CI [−0.51; −0.27], Figure 2).

Sentence perception test results and DoD were likewise associated with a medium negative correlation in 22 studies with 1024 patients (Random effects model; COR −0.43; 95%—CI [−0.53; −0.33], Figure 3).

A sensitivity analyses included 50% of the most recent studies. The result did not differ significantly for monosyllabic speech perception tests (COR −0.34 [−0.49; −0.17], Fisher's $z = 1.32$, $P = .19$), rather for sentence perception tests (COR −0.31 [−0.45; −0.15], Fisher's $z = -2.23$, $P = .02$).

3.4 | Subgroup analysis: Time of postoperative testing

After activation of the CI processor, patients need to adapt to the new hearing experience. Studies suggest that with postlingually deafened cochlear implantees, hearing perception improves the most within the first 3 to 6 months after the CI surgery[63,64] and plateaus after 1 to 2 years,[35,65-67] in contrast to prelingually deaf patients with constant improvement, for example, over a 4-year period.[8]

The studies included performed their postoperative testing between 2 weeks to 14 years. Figure S1 "Correlation coefficients for different post-intervention intervals" displays all Pearson correlation coefficients for DoD/CI performance across different testing points. The subgroup analysis of studies with a follow-up of less than 12 months revealed a strong negative correlation of COR −0.50 [−0.72; −0.20] for monosyllabic perception and medium negative correlation of COR −0.45 [−0.57; −0.32] for sentence perception. With a follow-up of more than 12 months (up to 14 years), only a moderate correlation could be calculated for monosyllabic perception (COR −0.32 [−0.42; −0.21]) and sentence perception COR −0.42 [−0.59; −0.22].

3.5 | Subgroup analysis: mean duration of deafness

The DoD of the patients included in the studies ranged from 0.1 to 77 years. Two subgroup analyses compared the studies with 50% of the shortest and longest DoD leading to a cutoff of more and less than 12 years. Results showed evident differences, indicating a poorer

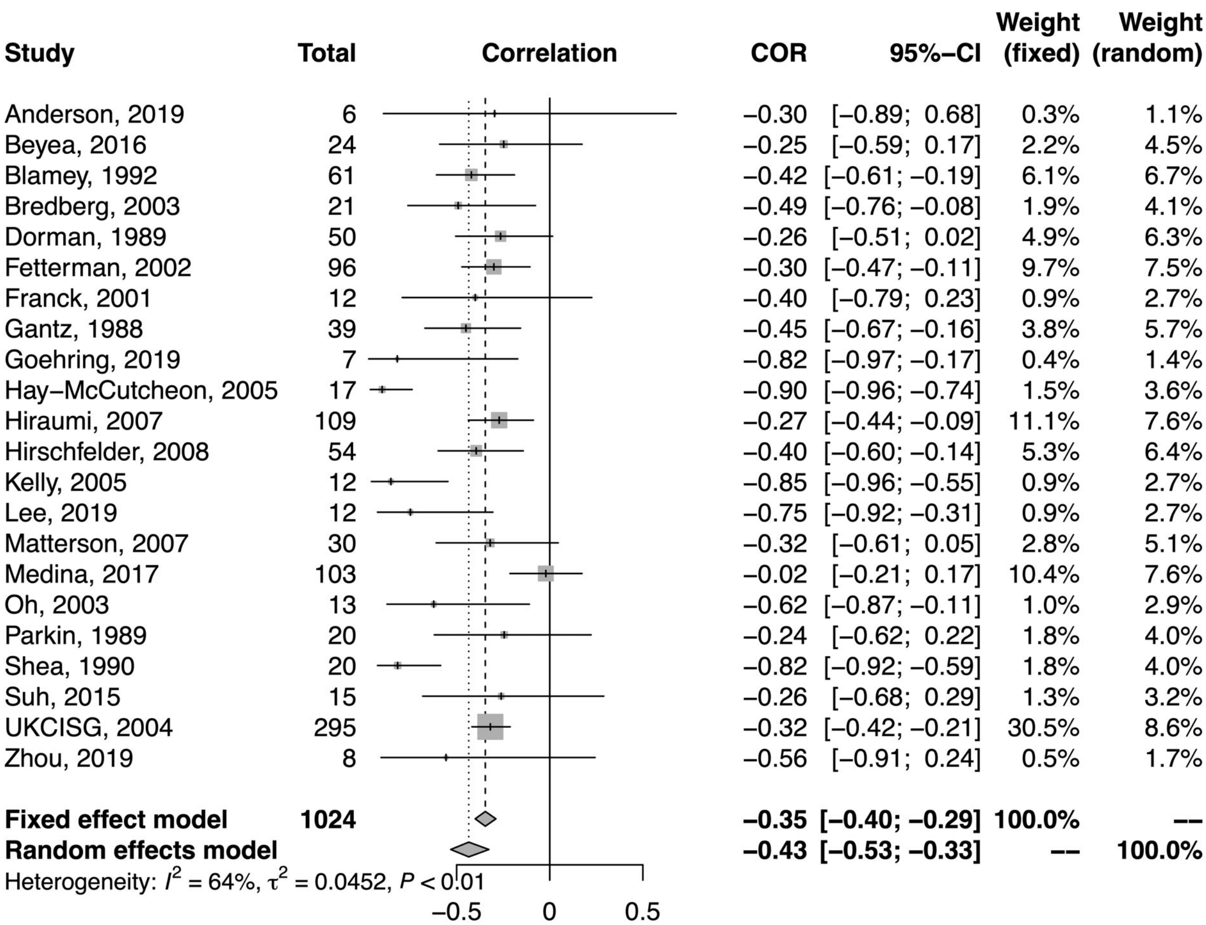

FIGURE 3 Meta-analysis of sentence tests. The forest-plot indicates the correlation between the preoperative duration of deafness and the postoperative scores of speech tests for sentences. Total: number of investigated patients

performance for the latter (monosyllabic subgroups: mean DoD < 12 years: COR −0.27 [−0.41; −0.12]; mean DoD > 12 years: COR −0.42 [−0.52; −0.31]; Fisher's z = −2.79, P = .005; sentence subgroups: mean DoD < 12 years: COR −0.32 [−0.45; −0.18], mean DoD > 12 years: COR −0.55 [−0.69; −0.37]; Fisher's z = −4.48, P < .001). Furthermore, there is a notable difference between the correlation of monosyllabic and sentence perception with DoD over 12 years (Fisher's z = −2.65, P = .008).

3.6 | Publication bias and risk of bias assessment

Publication bias was assessed by calculation of funnel plots, showing little evidence of asymmetry (Figure S2, Figure S3). The risk of bias assessment of all the studies included was performed using the QUADAS-2 tool and displayed in Figure S4a and Figure S4b. Only non-randomized studies were available, which often carry a high risk of bias in several different areas.

The patient selection methods were typically retrospective reviews, applying continuous inclusion without inappropriate exclusions. Several studies did not sufficiently elaborate the selection criteria to adequately assess bias. The speech perception tests were described thoroughly in most studies. However, the high variety of tests used might introduce bias regarding applicability. Major concerns arose from the vague definitions of deafness and determination of its duration. Therefore, the majority of studies were considered as carrying high risk in this area.

4 | DISCUSSION

DoD remains one of the most important predicting factors for CI performance outcome in postlingually deaf patients according to a multicenter analysis of 2251 patients.[68] Neural degeneration and cross-modal plasticity during long deafness are attributed to poor speech perception results.[51,69,70] Few studies took the duration of CI experience into account. Moreover, the delineation of DoD carries a high risk of recall bias and depends on a sudden or progredient onset. This review intends to present a synopsis of the numerous studies and clarify the impact of DoD on speech perception.

This systematic review included 36 studies indicating correlation coefficients of DoD and speech performance after cochlear implantation. Two meta-analyses show a significant overall medium negative correlation of sentence and monosyllabic word perception with length of hearing loss. Various investigations did not meet the inclusion criteria for the meta-analysis but reported important findings. The continuous stimulation of the cochlea via hearing aids has been shown to preserve neuronal hair cells[71] and therefore support better speech comprehension with CI.[72] A Composite Score[73] and Composite Index[74] were proposed to measure CI performance, the latter including prosodic characteristics, lip-reading enhancement, phonetic level, spondee tests and open-set speech recognition.

Studies revealed that DoD can lead to modifications of cortical and subcortical brain regions in patients with asymmetric as well as bilateral hearing loss.[75-77] In patients with single-sided deafness, the impact on CI outcome is less notable.[78] Inflammatory processes were identified to influence speech perception in this subgroup.[79] Studies investigated methods to visualize the brain metabolism preoperatively and formulate assumptions on possible CI outcome.[41,51] Several predictive models were developed to foresee CI performance,[4,7,26,80] for example, a mathematical formula to anticipate CI rehabilitation success including DoD and psychoacoustic data.[81] Remarkably, a multicenter review associated different speech coding strategies to CI performance rather than to other individual characteristics.[82] An interesting recent meta-analysis examined the effect of patient related factors on speech recognition outcomes (13 studies including 1095 patients).[83] In their analysis, a weak negative association was present for age at implantation and sentence recognition. DoD showed a negative correlation for word recognition after implantation only. Further correlations between CI performance and preimplant pure tone average or preimplant speech perception were interpreted to be negligible.

In one of the current subgroup analyses of different DoDs, the comparison showed a clear benefit of shorter time of auditory deprivation (≤12 years) and a more notable negative effect on sentence perception. A retrospective analysis of 1355 patients observed similarly worse hearing performance among long-term deaf patients in sentence comprehension tests compared to monosyllabic perception tests. The authors additionally stressed a positive effect of intensive postoperative rehabilitation.[66]

Our subgroup analysis on time of postoperative testing supports the observation that the effect of CI experience on the level of speech perception surpasses that of DoD.[68] The difference in monosyllabic perception for either a follow-up of more or less than 12 months (Fisher's z = 3.36, P = .001) might be explained by a poorer performance in the early phase after implantation for patients with longer DoD. With more CI experience, the gap between those with less and longer auditory deprivation time seems to narrow. The correlation with sentence perception is similar for both follow-up intervals, hence patients might rely on context intelligibility. The mean time to acquire maximum scores varied vastly in the available literature.[35,84] An investigation of postoperative long-term stability in 1005 postlingually deafened adults with a mean DoD of 7 years found that after an initial learning phase of 6 months after CI, performance remained at a stable level for more than 20 years.[64] Other studies observed a noteworthy increase of hearing perception in postlingually deaf adults for 3 years,[85] and a flatter rate of progress thereafter.[86] Figure S4 displays the heterogenous data of all r_P for DoD / CI performance across different points of testing. Five studies published r_P values for several points in time, hence an association with length of CI use can be inferred, for example, a r_P-decrease after 18 months compared to 1 month after implantation,[24] indicating a worse long-term outcome for those with higher DoD. However, other investigations found either weaker[47,56] correlations or unaffected outcomes over time.[38,39]

Several authors noted a difference in CI outcomes in patients with a shorter DoD of <5 years and a more rapid recovery of speech perception.[8,17,87,88] However, a significant difference in patients with divergent DoDs was found when DoD exceeded more than 30 years.[20,42,66]

DoD influences the CI outcome in all age groups.[89,90] The important confounding variable of age was examined in younger adults (n = 875) compared to geriatric patients (n = 130) with similar learning curves for the first 2 years of CI use.[91] A matched analysis of 28 patients demonstrated that after cochlear implantation in younger adults (mean age 43), the improvement of speech perception was 10% per month in the first 6 months, whereas in the older group (mean age 63), it was only 4%. The improvement curves flatten in both groups to about 2% improvement per month in the 24-month post-operation interval.[92]

The impact of DoD and age on CI performance is defined as DURAGE.[73] It describes the ratio of DoD in relation to years of sufficient hearing. DURAGE has a significant influence on the speech perception results independent of DoD. Thus, several authors coincide that the bigger the portion of a patient's lifetime spent with deafness, the poorer is language understanding with CI.[40,80]

There is an ongoing discussion of how to face cognitive decline in CI candidacy, since it may be associated with reduced CI outcome.[93,94] Tests of the olfactory and gustatory systems have been suggested to detect early signs of neurodegenerative disorders to offer prognostic information for possible low speech perception after implantation.[95,96] Conversely, new evidence shows a restored auditory function mitigates cognitive decline[97] for elderly patients above the age of 80 suffering profound hearing loss. A different study of 749 patients looked at the age groups below and above 65 years and recommends considering the DoD to age ratio compared with the individual values, since the older cohort interestingly outperformed the younger cohort when exceeding DoD of more than 25 years.[80] Therefore, age is not necessarily a limiting factor for CI candidacy.[17,98]

There is a risk of bias when comparing speech perception results from different languages and speech tests due to specific syntactic and phonetic characteristics. For our analyses, we grouped studies according to sentence and monosyllabic tests. The sensitivity analysis for sentence perception showed a weaker correlation with significant difference compared to the whole dataset. Likely confounders are a more heterogenous distribution of speech tests, ceiling effects particularly for sentence tests in quiet and the considerably longer follow-up periods in the subgroup of recent studies (on average 17 vs 34 months). The majority of the included studies were conducted in English-speaking countries. However, 11 different sentence intelligibility tests and 10 monosyllabic perception tests were used. In a comparison of multilingual postlingually deafened CI users with ossified cochlea, no significant impact of different languages was revealed.[24] Nevertheless, improvement efforts are undertaken to increase their comparability.[59] A benchmark study comparing different speech tests showed that 28% of the subjects achieved a speech perception performance of 100% with HINT sentences in quiet, whereas with a more demanding test (AzBio) only 0.7% of the subjects reached a test value of 100%. The latter reflected the hearing performance better in comparison to monosyllable word recognition (CNC) and sentence recognition in noise (BKB-SIN).[99] It was demonstrated that Freiburg numbers and monosyllables have a high assessment strength whereas CID showed weaknesses.[85] A recent investigation revealed that modern processors are associated with better CNC test results in contrast to HINT test results.[100]

With a topic as complex and internationally relevant as cochlear implantation, it is fundamental for scientific evidence to be able to compare study results globally. Therefore, in recent years there have been some remarkable initiatives to generate tools that try to overcome this obstacle. The International Collegium of Rehabilitative Audiology has formulated guidelines for the development of new multilingual speech tests, so called matrix tests, based on the initial work of Hagerman et al. which have become a useful and valid tool.[101-103] Due to the high international cross-language comparability of matrix tests, many international versions have been created.[59,103-106] Another approach is the use of standardized homogenous information collected from patients and examinations. For this purpose, the systematic data set for "minimal reporting standards" has been developed to improve long-term scientific comparability.[107]

Limitations for this systematic review result from the applied inclusion criteria and individual methods of included studies, since unclear residual hearing or uncertainty in hearing loss onset lead to an over or underestimation of the effect. Furthermore, no study was randomized nor controlled for one of the various contributing factors influencing postoperative speech perception. Authors regularly did not control for age, inner ear malformations, electrode array insertion or position within the cochlea.[108] In the present meta-analysis, 17 of the 36 studies reported speech reception results of 12 months or less. Hence, DoD cannot be held responsible as the single impacting factor for the negative correlation in this subgroup. One study investigated 15 variables, such as the device company, the number of active electrodes and the use of hearing aids preoperatively.[18] Often only patient history information is available, especially in cases of persistant deafness. The definition of deafness and its duration, if mentioned at all, varied vastly. Using "duration of bilaterally significant hearing loss" for a sound, homogeneous comparability was proposed. The definition consisted of 3 factors: the duration of bilateral severe hearing loss, the duration unable to use the telephone and the duration a patient had a speech recognition score of ≤30%.[109]

5 | CONCLUSION

DoD is one of the most important factors to predict speech perception after cochlear implantation in postlingually deaf patients. The meta-analyses revealed a negative correlation of DoD with postoperative sentence and monosyllable speech perception. Longer DoD results in worse CI performance, whereas more experience with CI mitigates the effect. Thorough characteristics of patients should be collected to conduct true multivariate analyses and to identify the effect of the various factors that influence speech perception individually.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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